Classical Cryptography

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Example and definitions of a cryptosystem

Caesar Cipher - the oldest cryptosystem

A *shift* cipher – attributed to Julius Caesar (100-44 BC)

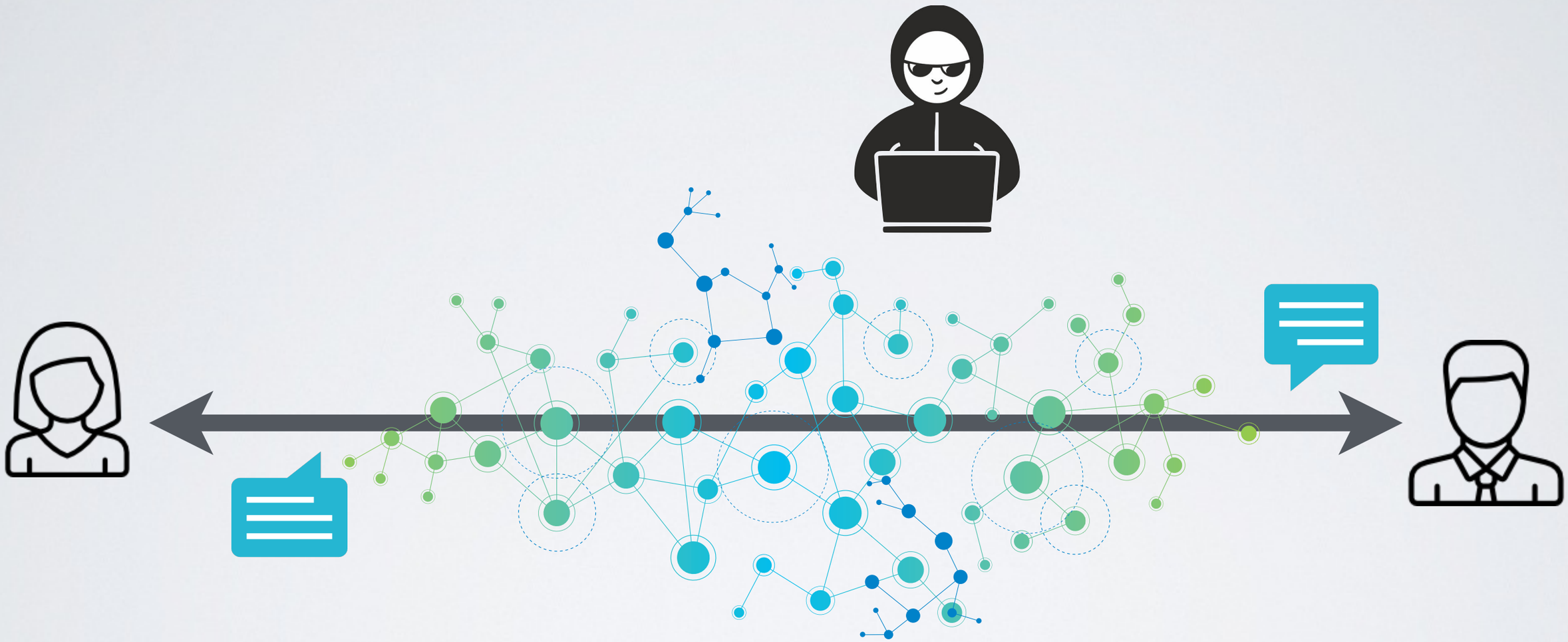
```
MEET ME AFTER THE TOGA PARTY
```

```
PHHW PH DIWHU WKH WRJD SDUWB
```

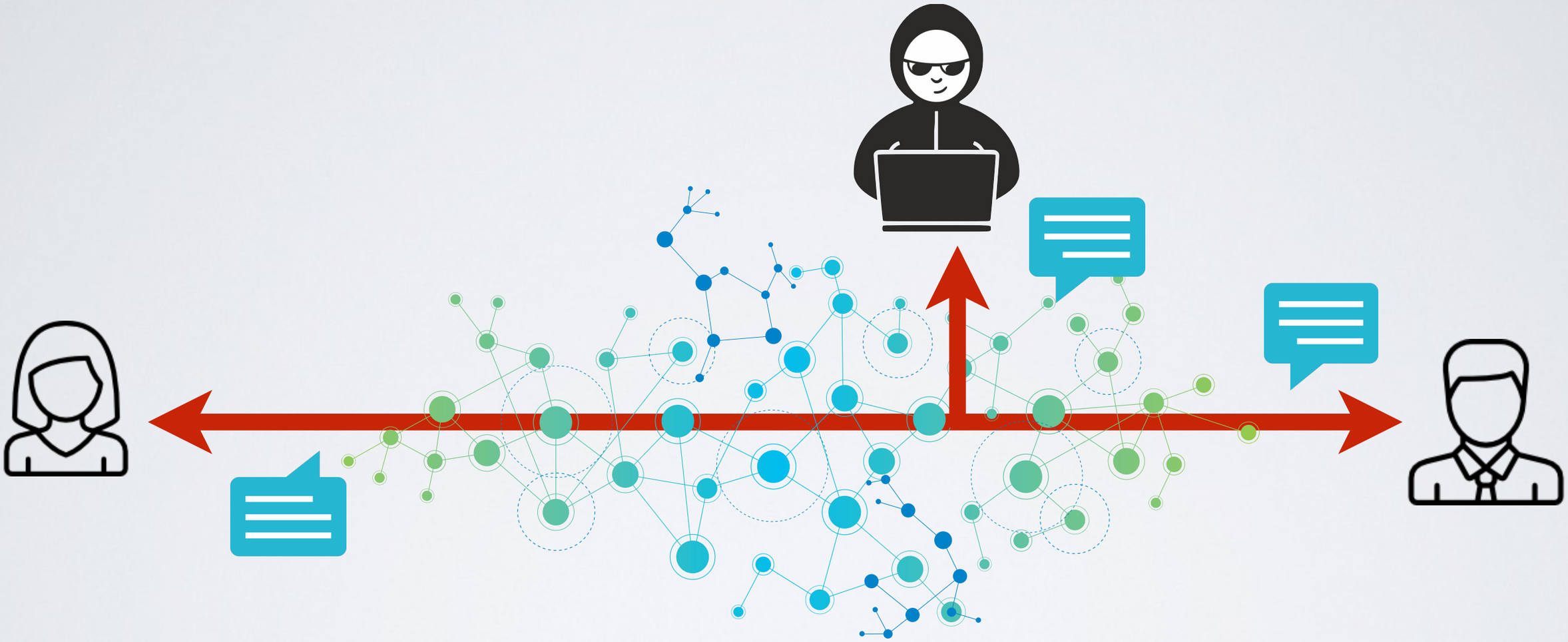
Shift the alphabet 3 places further down and substitute letters

```
a b c d e f g h i j k l m n o p q r s t u v w x y z
D E F G H I J K L M N O P Q R S T U V W X Y Z A B C
```

Communication over an **insecure** medium

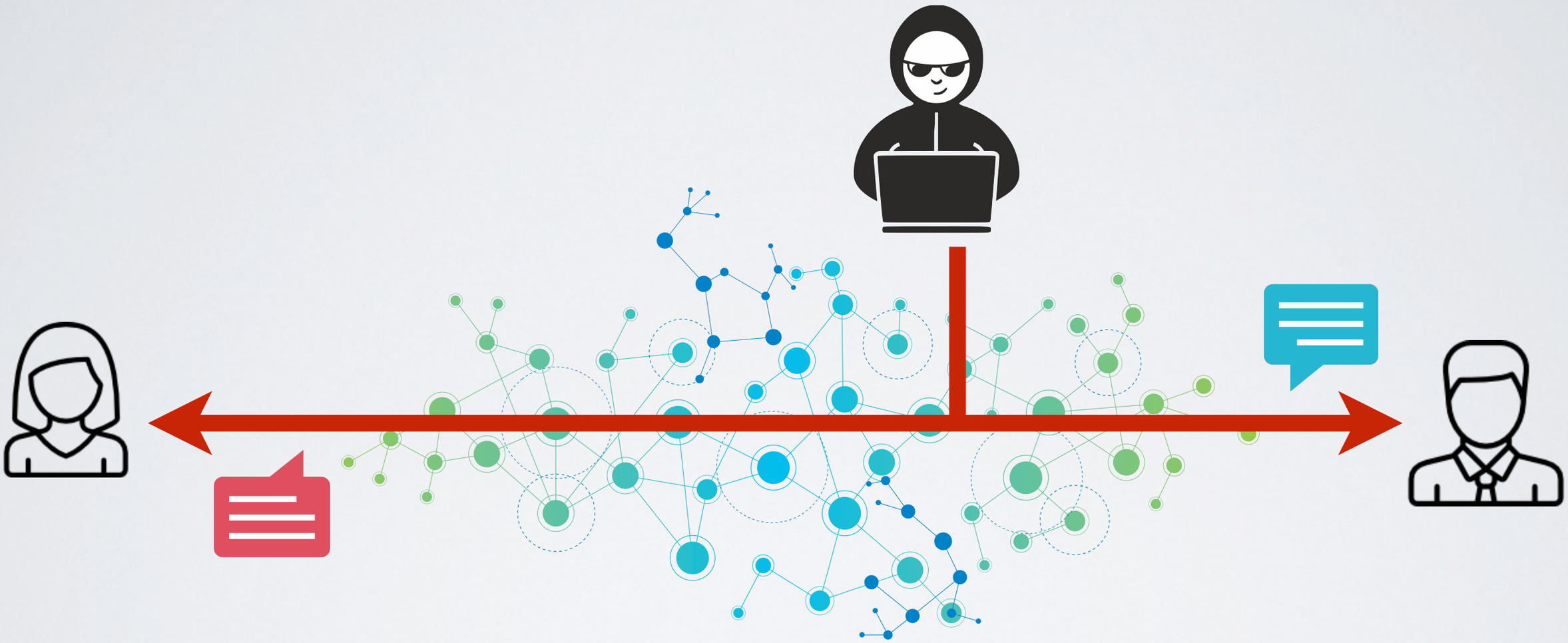


Threat 1 - **Interception**



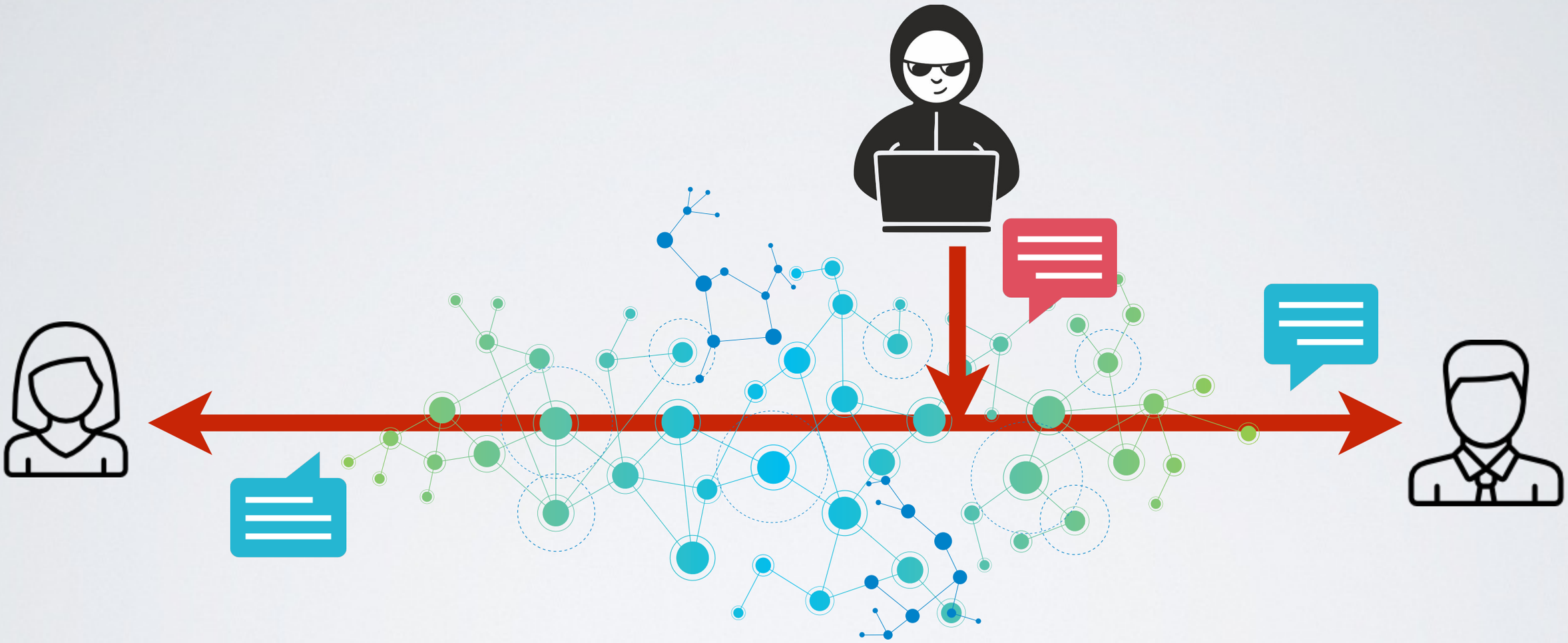
- **Interception** : an attacker can <u>read</u> messages

Threat 2 - **Modification**



- **Modification** : an attacker can <u>modify</u> messages

Threat 3 - **Fabrication**



- **Fabrication** : an attacker can inject messages

Threat 4 - **Interruption**

- **Interruption** : an attacker can block messages

Confidentiality and Integrity of communications

➡ Implement a **virtual trusted channel** over an insecure medium

Definitions

Plaintext
The message in its clear form (the original message)

Ciphertext
The message in its ciphered form (the encrypted message)

Encryption
Transform a plaintext into ciphertext

Decryption
Transform a ciphertext into a plaintext

Definitions

Cryptographic algorithm
The method to do encryption and decryption

Cryptographic key
An input variable used by the algorithm for the transformation

N-bit security entropy (a.k.a. the key space)
The number of bits necessary to encode the number of possible keys (could be different than the key length)

Representing data as numbers

Cryptographic algorithms are mathematical operations

- ➡ messages and keys must be represented as numbers
  for instance : ASCII encoding

Back to Caesar Cipher

Algorithm : shift the alphabet of a certain number of positions

Key : the number of positions to shift

Key space : 25 possible rotations (~ 5 bits security)

Encoding :

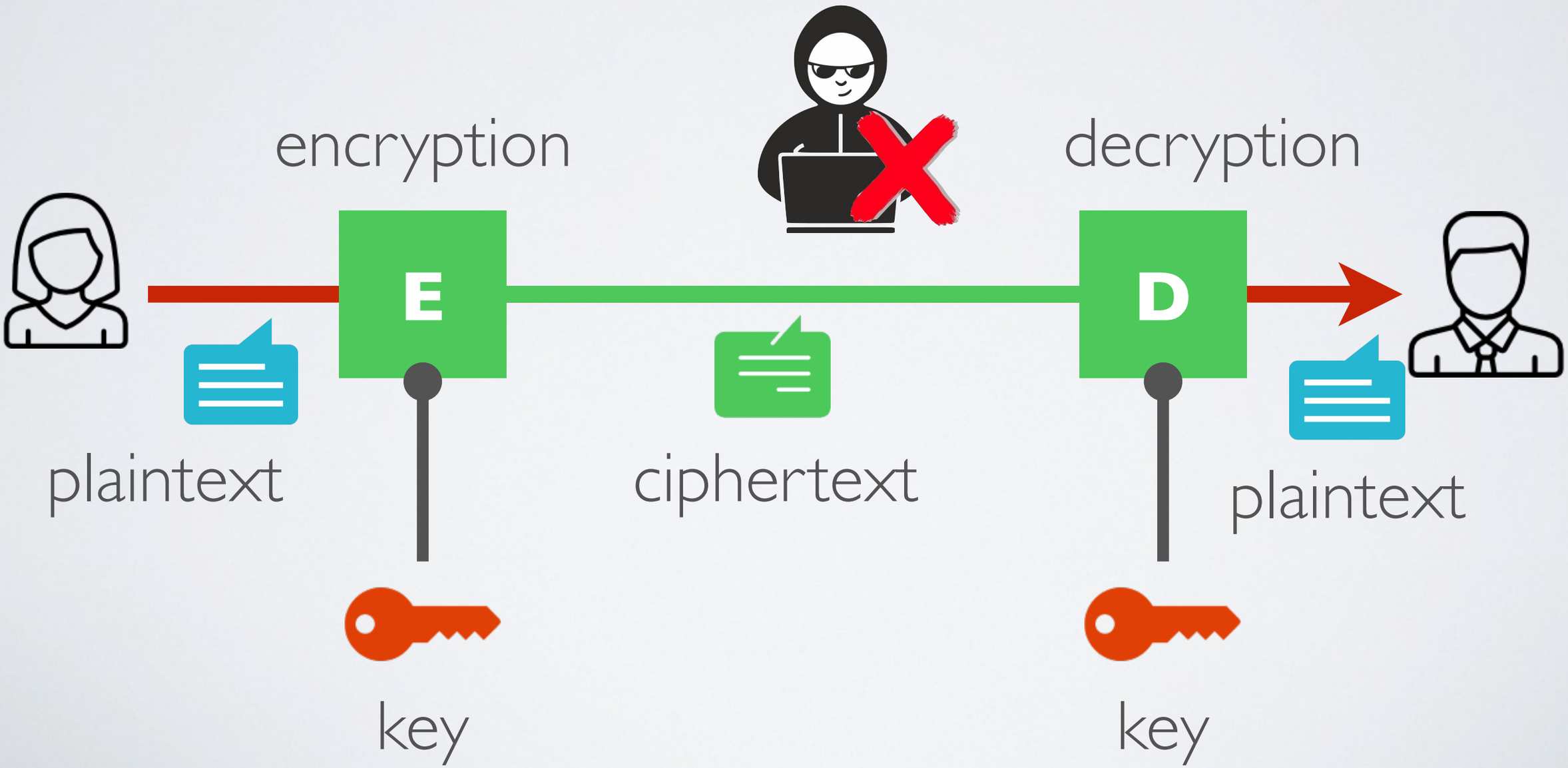
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Encrypting and decrypting one character is obtained as follows:

$$c = E(k,p) = (p + k) \bmod 26$$

$$p = D(k,c) = (c - k) \bmod 26$$

The big picture



Breaking the cipher

The Kerckhoffs' principle (1883)

"The enemy knows the system" - the security of a communication should not rely on the fact that the algorithms are secrets

➡ A cryptosystem should be secure even if everything about the system, except the key, is public knowledge

No security by obscurity

Breaking the cipher - the attacker's model

- **Exhaustive Search** (a.k.a brute force)
  Try all possible n keys (in average it takes n/2 tries)

- **Ciphertext only**
  You know one or several random ciphertexts

- **Known plaintext**
  You know one or several pairs of random plaintext and their corresponding ciphertexts

- **Chosen plaintext**
  You know one or several pairs of chosen plaintext and their corresponding ciphertexts

- **Chosen ciphertext**
  You know one or several pairs of plaintext and their corresponding chosen ciphertexts

➡ **A good crypto systems resist all attacks**

Breaking Caesar cipher

Exhaustive search	Yes
ciphertext only	Statistical Analysis
known plaintext	Look at the first letter and get the shift
chosen plaintext	Choose “A” and get the shift
chosen ciphertext	Choose “A” and get the shift

Statistical Cryptanalysis

- Monoalphabetic ciphers do not change the relative frequency of letters in a message

Evolution of cryptosystems

A brief history of cryptography

~ 2000 years ago	Substitution ciphers (a.k.a mono alphabetic ciphers)
few centuries later	Transposition ciphers
Renaissance	Polyalphabetic ciphers
1844	Mechanization
1976	Public key cryptography

Substitution ciphers
(a.k.a mono alphabetic ciphers)

➡ Improvement over Caesar cipher

Algorithm : allow an arbitrary permutation of the alphabet

Key : set of substitutions

Key space : 26! possible substitutions ($4 \times 10^{26} \sim 89$ bits)

```
a b c d e f g h i j k l m n o p q r s t u v w x y z
D K V Q F I B J W P E S C X H T M Y A U O L R G Z N
```

```
if we wish to replace letters
WI RF RWAJ UH YFTSDVF SFUUFYA
```

Breaking substitution ciphers

Exhaustive search	Small key length only
ciphertext only	Statistical analysis
known plaintext	Match letters together
chosen plaintext	Choose ABCDE … and match letters
chosen ciphertext	Choose ABCDE … and match letters

Polyalphabetic ciphers (a.k.a Renaissance Cipher)

➡ Vigenere cipher

Algorithm : combine the message and the key

Key : a word

Key space : the length of the word

$$\begin{array}{rl} & \texttt{wearediscoveredsaveyourself} \\ + & \texttt{deceptivedeceptivedeceptive} \pmod{26} \\ \hline & \texttt{ZICVTWQNGRZGVTWAVZHCQYGLMGJ} \end{array}$$

Advantage : Encryption of a letter is context dependent

Breaking Polyalphabetic Ciphers

exhaustive search	Small key length only
ciphertext only	Statistical analysis for small key length and significant amount of ciphertext
known plaintext	Subtract plaintext from ciphertext
chosen plaintext	Choose AAAAA … and match letters
chosen ciphertext	Choose AAAAA … and match letters

OTP - One Time Pad

➡ Improvement over Vigenere cipher

Algorithm : combine the message and the key

Key : an infinite random string

Key space : infinite

```
  whatanicedaytoday
⊕ yksuftgoarfwpfwel
------------------
  ZZZJUCLUDTUNNWGQS
```

Advantage : this is the perfect cipher !

Disadvantage : hard to use in practice, how to transmit the key ?

The impossibility of breaking OTP

The ciphertext bears no statistical relationship to the plaintext

➡ No statistical analysis

For any plaintext and ciphertext, there exists a key mapping one to the other, and all keys are equally probable

➡ A ciphertext can be decrypted to any plaintext of the same length

Transposition Cipher

Algorithm : switch letters around a permutation

Key : a set of permutation

Key space : the set of permutations

```
helloworld
LOLHERDLWO
```

Breaking Transposition ciphers

brute force	Small key length only
ciphertext only	Hard
known plaintext	Match letters together
chosen plaintext	Choose ABCDE … and match letters
chosen ciphertext	Choose ABCDE … and match letters

The seeds of modern cryptography

1. **Diffusion**
   Mix-up symbols
   Transposition Cipher

2. **Confusion**
   Replace a symbol with another
   Polyaphabetic Cipher

3. **Randomization**
   Repeated encryption of the same text are different
   OTP

Mechanization

Mechanization

1844	Invention of the telegraph
1939	World War II The Enigma Machine

The cryptography toolbox

Cryptography is not just a about confidentiality

Integrity
digital signatures, hash functions

Non-repudiation
contract-signing

Anonymity
electronic cash, electronic voting

…

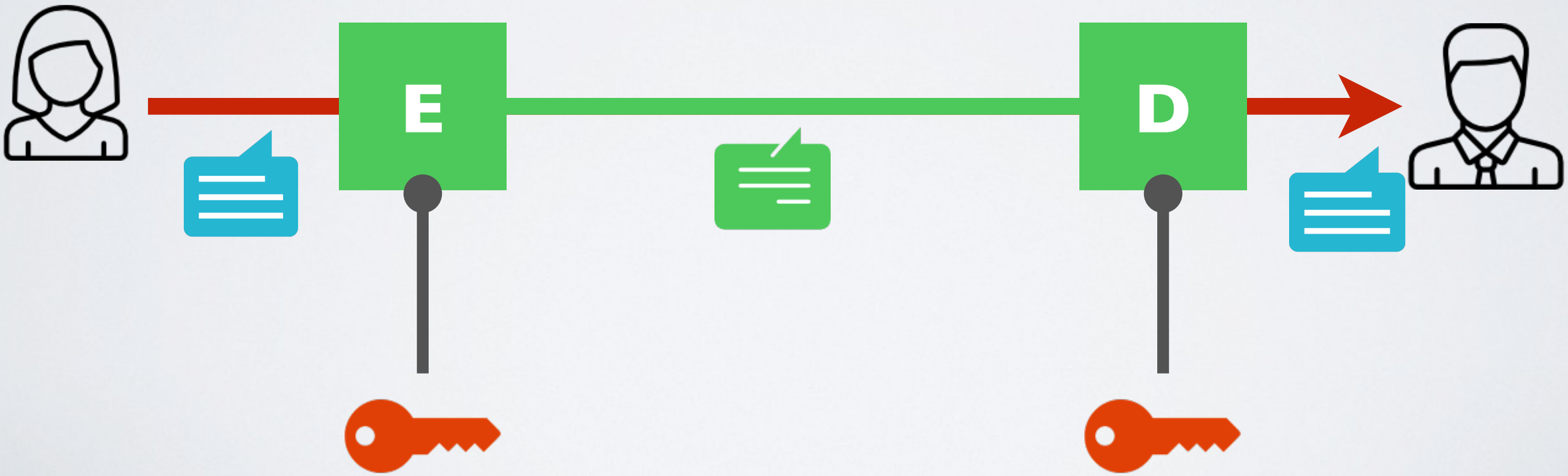
~~**Availability**~~

The crypto toolbox

- Symmetric cryptography schemes
- Asymmetric cryptography schemes
- Message digests
- Digital signatures
- Certificates

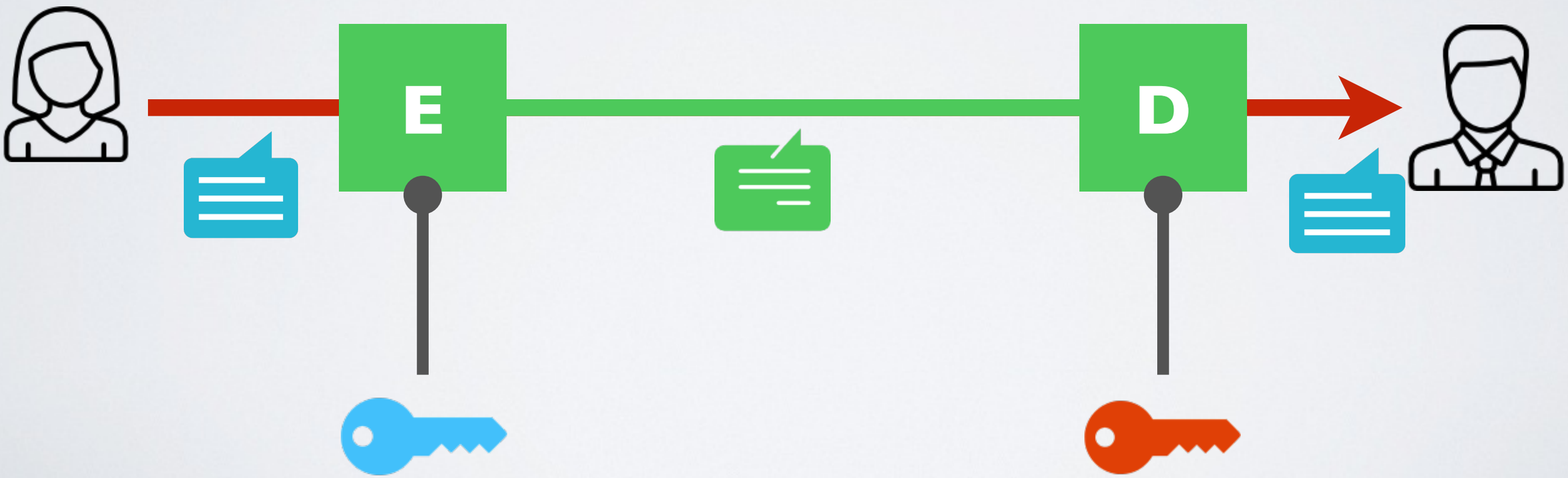
Symmetric encryption

➡ The same key is used for encryption and decryption



Asymmetric encryption
a.k.a Public Key Cryptography

- ➡ The public key for encryption
- ➡ The private key for decryption



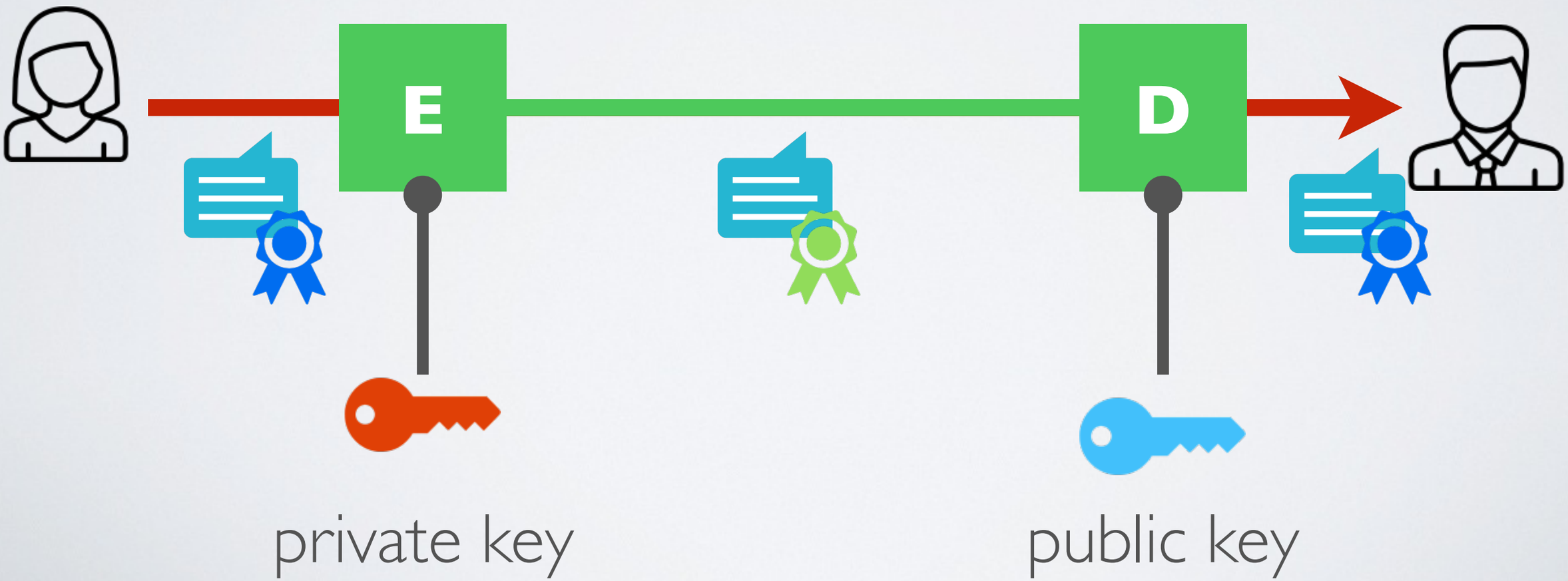
Message digests

Message digests are meant for creating fingerprints of messages

- Un-keyed message digest : hashes, checksum
- Keyed message digests : MACs

Digital Signature

- The private key for encryption
- The public key for decryption



Certificates - Public Key Infrastructure

Certificates are meant for verifying someone's identity

- Binding between a public key and an owner
- Certified by a certification authority